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DO ADJUSTING-AMOUNT AND ADJUSTING-DELAY PROCEDURES PRODUCE EQUIVALENT ESTIMATES OF SUBJECTIVE VALUE IN PIGEONS?

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The current experiment examined whether adjusting-amount and adjusting-delay procedures provide equivalent measures of discounting. Pigeons' discounting on the two procedures was compared using a within-subject yoking technique in which the indifference point (number of pellets or time until reinforcement) obtained with one procedure determined the value of the corresponding variable in the yoked condition with the other procedure. Behavior on each procedure was well described by a hyperbolic discounting function. Results revealed no systematic differences in the degree of discounting as measured by the discounting rate parameter of the hyperbola in Experiment 1, which used 20-mg pellets. These results were replicated in Experiment 2 using smaller, 14-mg pellets, which potentially yield more precise measurement of indifference points on the adjusting-amount procedure. The finding that estimates of the *k* parameter in the hyperbolic discounting function obtained with one procedure did not differ systematically from estimates obtained from the same subjects with the other procedure represents strong support for the hypothesis that the same process underlies the discounting of delayed rewards on both adjusting-amount and adjusting-delay procedures.

Key words: discounting, subjective value, adjusting amount, adjusting delay, hyperbolic function, key peck, pigeons

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As the delay until the receipt of a reward increases, the present (subjective) value of the reward decreases. This is evidenced by the fact that organisms frequently choose a smaller reward available sooner over a larger reward available at a later time (e.g., Ainslie, 1975, 1992; Mazur, 1987; Mischel, Shoda, & Rodriguez, 1989; Rachlin & Green, 1972). The systematic decrease in the present value of a reward as the delay to its receipt increases is often termed temporal discounting (for a recent review, see Green & Myerson, 2004).

A temporal discounting function describes the relation between the delay to a reward and its subjective value. This function is frequently written as

$$V = A/(1 + kD), \qquad (1)$$

where V represents the subjective value of a reward of amount A, D represents the delay until its receipt, and k governs the rate of discounting (Mazur, 1987).

Mazur (1987) developed an adjusting-delay procedure for use in determining the amount of a smaller, sooner reward that makes it equivalent in value to a larger, later reward. In his Experiment 1, for example, he had pigeons choose between 2 s of access to grain delivered after a brief, fixed delay and 6 s of access to grain delivered after a longer, adjustable delay. If a pigeon chose the 2-s reward twice in a row, then the delay to the 6-s reward was decreased. Alternatively, if the pigeon chose the 6-s reward twice in a row, then the delay until this reward was increased. When both alternatives were chosen approximately equally often, the present, subjective values of the two rewards were assumed to be equivalent. In different conditions of the experiment, Mazur varied the delay to the 2-s reward and showed that the delay to the 6-s reward that made the values of the two rewards equivalent was accurately predicted by Equation 1.

In contrast, research on temporal discounting in humans has tended to use an adjusting-amount procedure (Rachlin, Raineri, & Cross, 1991) rather than an adjusting-delay procedure. Richards, Mitchell, de Wit, and Seiden (1997) developed an adjusting-amount pro-

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cedure for use with rats that combined elements of the procedures used by Mazur (1987) and Rachlin et al. In their Experiment 1, for example, Richards et al. had rats choose between a small amount of water, available immediately, and a larger amount (100 μL) available after a fixed delay. If a rat chose the smaller, immediate reward, then the amount of the smaller reward was decreased by 10% on the next trial, whereas if the rat chose the larger, later reward, then the smaller reward was increased by 10%. In different conditions, Richards et al. varied the delay to the larger, later reward in order to map out a temporal discounting function. Similar results have been obtained using an adjusting-amount procedure with pigeons (Green, Myerson, Holt, Slevin, & Estle, 2004). In both cases, the data, like those from the adjusting-delay procedure studied by Mazur, were well described by a simple hyperbola (Equation 1).

The fact that data from both the adjusting-amount and the adjusting-delay procedures can be described by the same hyperbolic mathematical function raises the possibility that the two procedures yield equivalent estimates of discounting. This hypothesis has never been explicitly tested, however, and there are reasons, both theoretical and empirical, to suspect that it might be false.

First, it is known that humans make different choices depending on how the options are described. Kahneman and Tversky (1979) explain how such behavior can result from shifts in the reference point against which the options are judged. In addition to the well-known effect that describing outcomes as gains or losses has on decision making (Tversky & Kahneman, 1981), Loewenstein (1988) has shown that reference points affect decisions involving intertemporal choice situations in which the options are both gains. It is possible that different intertemporal choice procedures might establish different reference points depending on which variable is held constant and which is varied (e.g., amount or delay), which then would lead to differences in behavior on adjusting-amount and adjusting-delay procedures.

Second, when Mazur (2000) estimated k in pigeons with adjusting-delay (Experiment 1) and adjusting-amount (Experiment 2) procedures, these estimates differed by a factor of two. This finding must be interpreted with caution, however, because different subjects were used in the two experiments, which differed in other aspects of the procedures in addition to which variable was adjusted. In contrast, the present study provides an explicit test of the equivalence of discounting rates estimated with adjusting-amount and adjusting-delay procedures using the same subjects.

We compared indifference points in two ways, each of which used a within-subject yoking technique. In one method, pigeons were first exposed to an adjusting-amount procedure in which the amount of an immediate reward was adjusted until it was judged equal in value to a fixed larger amount of delayed reward. The pigeons then were exposed to a yoked adjusting-delay procedure in which they chose between the larger, delayed reward and the immediate amount determined previously, adjusting the delay until the later reward was judged equal in value to the immediate reward. If the two procedures converge on similar estimates of the indifference point, then the length of the adjusted delay from the adjusting-delay procedure would be approximately equal to the length of the fixed delay in the preceding adjusting-amount procedure. For example, consider a pigeon that first was exposed to an adjusting-amount procedure in which a larger, 30-pellet reward was available after a 3-s delay, followed by an adjusting-delay procedure. If the present, subjective value of the 3-s delayed reward from the first procedure were determined to be 12 food pellets, then for the second, yoked procedure, the choice would be between an immediate, 12-pellet reward and 30 food pellets available after an adjustable delay. Would the pigeon adjust the delay to 3 s?

In the other method, the pigeons were exposed to the adjusting-delay procedure first, followed by a yoked adjusting-amount procedure. Having adjusted the delay to a large reward until it was judged equal in value to a smaller, immediate reward, they then chose between the large reward after that delay and the smaller, immediate reward, adjusting the amount of the latter until it was judged equal in value to the delayed reward. If the procedures converge on similar estimates of the indifference point, then the number of pellets for the adjusted, immediate amount from the second procedure would be approximately equal to the number for the fixed, immediate amount from the first procedure. For example, if the pigeon first was exposed to an adjusting-delay procedure in which the immediate reward was 5 pellets and the subjective value of this reward was determined to be equal to a 30-pellet reward delayed by 14 s, then for the second, yoked procedure, the choice would be between 30 pellets available after 14 s, and an adjustable amount of immediate reward. Would the pigeon adjust the immediate amount to 5 pellets?

Also at issue in this study was whether a single hyperbolic discounting function would describe data obtained using both the adjusting-amount and adjusting-delay procedures. If different discounting functions were to prove necessary, such a result would suggest that pigeons evaluate delayed rewards differently depending on which aspects of the choice situation are held constant and which are varied. In contrast, if the same function were to describe the data from both procedures, this result would be consistent with the widely held assumption that delayed rewards are evaluated similarly regardless of which aspects of the situation are varied.

EXPERIMENT 1

Method

Subjects

Seven White Carneau pigeons, all retired breeders, were housed individually in an animal colony room under a 12:12 hr light/dark cycle. They were maintained at between 80 and 85% of their free-feeding weights through supplemental feedings following daily sessions; health grit and water were continuously available in their home cages.

Apparatus

Two experimental chambers (Coulbourn Instruments), 30.5 cm long × 25.5 cm wide × 30.5 cm high, were located inside sound- and light-attenuating enclosures ventilated by fans. A MED Associates interface and MED-PC™ for Windows software controlled the presentation of stimuli and recorded responses. Each chamber was equipped with a video camera that allowed for continuous, unobtrusive monitoring of the experiment.

Within each chamber, three circular response keys were mounted on the front wall. Each key was 2.5 cm in diameter and required a force of at least 0.15 N to operate. The middle key was centered horizontally on the wall, 20 cm above the grid floor; the left and right keys were positioned 8.5 cm to either side of the middle key, center-to-center, and 24 cm above the floor. When lit, the middle key was yellow, and the left and right keys were red and green, respectively. A triple-cue lamp was located 7.5 cm above the middle key. The colors of the LEDs were (from left to right) red, yellow, and green, corresponding to the colors of the three response keys. A 7-W houselight was located in the center of the ceiling.

Reinforcement consisted of varying numbers of 20-mg Noyes Precision food pellets (pigeon formula C1) delivered to either of two food magazines. The openings of the food magazines measured 4 cm high by 5 cm wide and were located directly beneath the left and right keys, with the bottom of each magazine opening located 1.5 cm above the chamber floor. During reinforcement, the operative magazine was illuminated with white light, and all other lights in the chamber were extinguished. Food pellets were delivered at a rate of one every 0.3 s, and infrared photodetectors were used to sense whether there were pellets left in the magazine.

Procedure

Each pigeon was exposed to four pairs of adjusting-amount and adjusting-delay procedures, in two of which the adjusting-amount procedure came first, followed by a yoked adjusting-delay procedure, and in the other two of which the adjusting-delay procedure came first, followed by a yoked adjusting-amount procedure.

More specifically, if the adjusting-amount procedure came first, then its results were used to determine the immediate amount in the second, adjusting-delay procedure; if the adjusting-delay procedure came first, then its results were used to determine the time to the delayed amount in the second, adjusting-amount procedure. When an adjusting-amount procedure came first, the time to the delayed reward was either 3 s or 10 s. When an adjusting-delay procedure came first, the amount of the fixed, immediate reward was

Table 1

Order in which pigeons experienced pairs of adjusting-amount (AA) and adjusting-delay (AD) procedures in Experiment 1.

	First Procedure of Pair			
Pigeon	AD 5 pellets immediately	AD 15 pellets immediately	AA 30 pellets after 3 s	AA 30 pellets after 10 s
81	1	2	4	3
82	1	2	3	4
83	2	1	4	3
84	2	1	3	4
91	4	3	1	2
92	3	4	2	1
93	3	4	2	1

either 5 pellets or 15 pellets. The amount of the delayed reward was 30 pellets throughout the experiment. Four of the pigeons (81–84) began with an adjusting-delay procedure followed by a yoked adjusting-amount procedure, and the other 3 pigeons (91–93) began with an adjusting-amount procedure followed by a yoked adjusting-delay procedure (see Table 1).

With the adjusting-amount procedure, the choice was between 30 pellets delivered after a fixed delay (either 3 s or 10 s), and a smaller, variable number of pellets, delivered after a very brief (i.e., 0.5 s) delay. Because it takes pigeons approximately 0.5 s after a peck on a response key to reach the food magazine (Mazur, 2000), pellets delivered after a 0.5 s delay will be referred to as ‘‘immediate’’ rewards. The number of immediate pellets depended on a pigeon's previous choices. Pecks on the left key produced the smaller (variable), immediate reward amount, and pecks on the right key produced the larger (fixed), delayed reward amount.

With the adjusting-delay procedure, the choice was between 30 pellets delivered after a relatively long, variable delay, the duration of which depended on a pigeon's previous choices, and a smaller, fixed number of pellets (5 or 15), delivered immediately. Pecks on the left key produced the smaller immediate reward amount, and pecks on the right key produced the larger reward amount after a longer (variable) delay.

For both procedures, daily sessions consisted of 10 blocks of four trials each. Each block consisted of two forced-choice trials on which only one side key was illuminated, followed by two free-choice trials on which both side keys were illuminated. The order of the forced-choice trials was randomly determined such that on half of the blocks, the first forced-choice trial was on the left key, and on the other half, the first forced-choice trial was on the right key. Onset of a trial was signaled by offset of the houselight and onset of the middle (yellow) keylight. A single peck darkened the middle key and illuminated either a single side key (forced-choice trials) or both side keys (free-choice trials). Following a response to an illuminated side key, the side key(s) darkened and the appropriate cue lamp (the one corresponding to the side key that had been pecked) was illuminated. This lamp remained lit during the delay to food delivery, at which time it was extinguished. The food magazine remained lit for at least 10 s and was not extinguished until all food was consumed, as determined by the photo-detectors.

After all pellets were consumed and at least 10 s had elapsed, the magazine light was extinguished and the houselight reilluminated. Food presentations were followed by an intertrial interval, the duration of which was adjusted so that the total time from the onset of one trial to the onset of the next trial was held constant at 70 s.

After each block of four trials (two forced-choice and two free-choice trials), either the immediate amount (on the adjusting-amount procedure) or the delay to the larger amount (on the adjusting-delay procedure) was redetermined. For the adjusting-amount procedure, if the pigeon chose the right (delayed reward) key on both free-choice trials, then the immediate amount was increased by 1 pellet for the next block of trials; if the pigeon pecked the left (immediate reward) key on both free-choice trials, then the immediate amount was reduced by one pellet for the next block of trials. If the pigeon chose each key once, then the immediate amount remained unchanged.

For the adjusting-delay procedure, if the pigeon chose the right (delayed reward) key on both free-choice trials, then the delay to the larger amount was increased by 1 s for the next block of trials. If the pigeon chose the left (immediate reward) key on both free-choice trials, then the delay to the larger amount was decreased by 1 s for the next block of trials. If the pigeon chose each key once, then the delay remained unchanged.

As noted previously, each pigeon completed four pairs of adjusting-amount and adjusting-delay procedures, with the results from the first procedure of the pair determining the parameters for the second, yoked procedure. Pigeons were exposed to each procedure for a minimum of 15 sessions and until their data from 5 consecutive sessions were judged stable. Individual stability criteria were evaluated by dividing each session into 2 half-sessions of five trial-blocks each. For each half-session, the mean number of food pellets (for adjusting-amount procedures) or seconds (for adjusting-delay procedures) was calculated. A pigeon's performance on a given procedure was considered stable when the means for the 10 half-sessions were within two pellets or 2 s (for adjusting-amount and adjusting-delay procedures, respectively) of the grand mean and there was no visible trend. The median numbers of sessions to stability on the adjusting-amount and adjusting-delay procedures were 22 (range = 15–102) and 24 (range = 15–73), respectively.

Results and Discussion

Figure 1 shows the discounting data for each pigeon as well as the group means. Each pair of same-shaped symbols (e.g., triangles) represents a pair of yoked conditions. Visual inspection of Figure 1 reveals no obvious systematic differences between the adjusting-amount data (filled symbols) and the adjusting-delay data (open symbols). Nonlinear least squares fits to the data were obtained using SigmaPlot™ 9.0 software, and the results of the fits confirm this impression. Analyses in which separate discounting functions (Equation 1) were fit to the adjusting-amount data and the adjusting-delay data from each individual subject revealed that for the adjusting-amount data, the mean of the individual k values was 0.492 (standard error = 0.075) with a mean R^2 of .860, and for the adjusting-delay data, the mean of the individual k values was 0.501 (standard error = 0.088) with a mean R^2 of .911. Statistical tests on these values found no significant difference between the procedures with respect to either the individual estimates of k or the R^2s; $t(6) = 0.12$ and 1.06, respectively. Because there were no systematic differences between the results from the two procedures, discounting functions were fit to the combined data from each individual as well as the group means. As may be seen in Figure 1, with the exception of P83, the data were well described by a simple hyperbola (Equation 1); the median R^2 for fits to individual data was .863, and the R^2 for the fit to the group means was .946.

The present results suggest that relatively similar degrees of discounting are observed on adjusting-amount and adjusting-delay procedures, and the data from both procedures yield discounting functions that are reasonably well described by a simple hyperbola. It may be recalled that when the data from the two procedures were analyzed separately, the adjusting-delay data were better described by a simple hyperbola, on average, than the adjusting-amount data, although the difference in R^2 was not statistically significant. It is possible that the difference in R^2 reflected the fact that the resolution with which the subjective value of the delayed reward could be measured was limited by the size (20 mg) of the food pellets used in Experiment 1. Therefore, we conducted a systematic replication of this experiment using smaller (14 mg) pellets in Experiment 2. The smaller size of these pellets allowed a greater number of pellets to be delivered without greatly increasing the total amount of food delivered. By using rewards consisting of a greater number of pellets, it may be possible to measure the present (subjective) value of delayed rewards with greater resolution.

EXPERIMENT 2

Method

Subjects

The 7 pigeons from Experiment 1 participated.

Apparatus

The apparatus was identical to that used previously aside from the use of a 14-mg pellet dispenser.

Procedure

The procedure was similar to that in Experiment 1. One difference, however, was that 14-mg food pellets delivered at a rate of

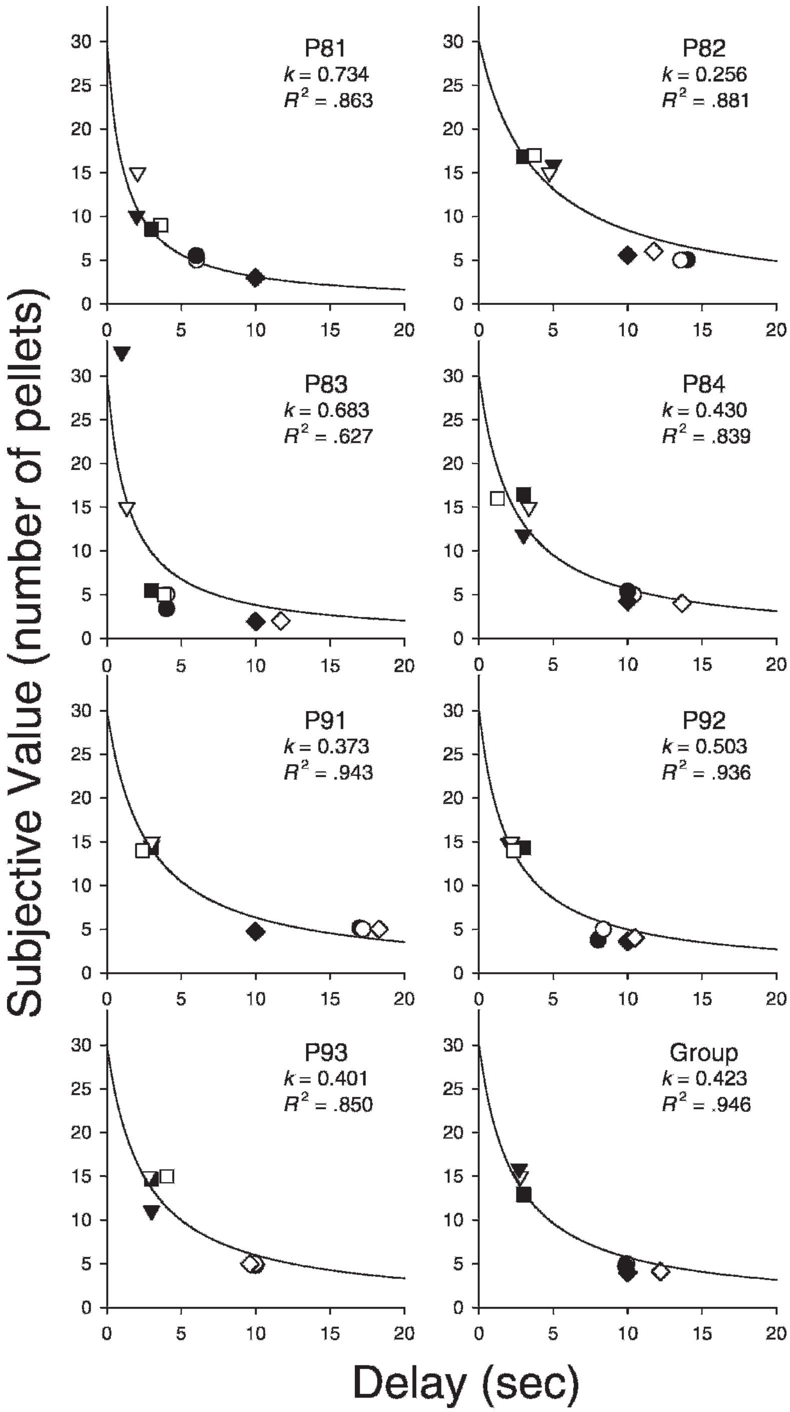

Fig. 1. Subjective value of the delayed 30-pellet reward as a function of time until its delivery. Data are from Experiment 1; results for individual pigeons, as well as group means (lower right graph), are shown. Open symbols represent data from the adjusting-delay procedure; filled symbols represent data from the adjusting-amount procedure. Each pair of same-shaped symbols (e.g., triangles) represents a pair of yoked conditions. Curves represent the best-fitting simple hyperbola (Equation 1).

Table 2

Order in which pigeons experienced pairs of adjusting-amount (AA) and adjusting-delay (AD) procedures in Experiment 2.

	First Procedure of Pair			
Pigeon	AD 10 pellets immediately	AD 25 pellets immediately	AA 50 pellets after 6 s	AA 50 pellets after 20 s
81	1	2	4	3
82	1	2	4	3
83	2	1	3	4
84	2	1	3	4
91	3	4	1	2
92	4	3	1	2
93	4	3	2	1

one every 0.6 s were used as reinforcement (rather than the 20-mg pellets delivered at the rate of one every 0.3 s used previously). Another difference was that the amount of the delayed reward in Experiment 2 was increased to 50 pellets.

The numbers of pellets delivered immediately on the adjusting-delay procedure and the times until delivery of the delayed reward on the adjusting-amount procedure also differed from those used in Experiment 1. With the adjusting-delay procedure, the amount of the immediate reward was either 10 or 25 pellets. With the adjusting-amount procedure, the delayed reward was delivered after either 6 s or 20 s. The order in which the pigeons experienced the different procedures is given in Table 2.

As in Experiment 1, each pigeon was exposed to four pairs of procedures, two of which consisted of an adjusting-amount procedure followed by a yoked adjusting-delay procedure, and two of which consisted of an adjusting-delay procedure followed by a yoked adjusting-amount procedure. Again, the results of the first procedure of a pair determined the parameters of the second, yoked procedure. The median numbers of sessions to stability in the adjusting-amount and adjusting-delay procedures were 27 (range = 16–113) and 26.5 (range = 15–95), respectively.

Results and Discussion

Figure 2 shows the discounting function for each pigeon and for the group based on data from both the adjusting-amount (filled symbols) and adjusting-delay procedures (open symbols). Each pair of same-shaped symbols (e.g., triangles) represents a pair of yoked conditions. As in Experiment 1, there appear to be no systematic differences between the adjusting-amount data and the adjusting-delay data, and the combined data from both procedures were reasonably well fit by a simple hyperbola (Equation 1); the median R^2 for fits to individual data was .853, and the R^2 for the fit to the group means was .974.

Analyses were conducted in which separate discounting functions were determined for data from the adjusting-amount and adjusting-delay procedures. For the adjusting-amount data, the mean of the individual k values was 0.511 (standard error = 0.076) with a mean R^2 of .788; for the adjusting-delay data, the mean of the individual k values was 0.467 (standard error = 0.035) with a mean R^2 of .913. There was no statistically significant difference between the procedures with respect to either the individual estimates of k or the R^2s; $t(6)$ = 0.62 and 1.51, respectively.

Overall, the degree of discounting in Experiment 2, as indexed by the value of the k parameter for the fit of Equation 1 to the group mean data, was very similar to that observed in Experiment 1; $k = 0.418$ vs. $k = 0.423$. The pattern of results obtained in Experiment 2, as reflected in comparisons of the data from the two procedures, was also similar to that in Experiment 1. Figure 3 shows the individual estimates of k for the adjusting-amount procedure plotted as a function of the individual estimates for the corresponding adjusting-delay procedure in both Experiment 1 (filled circles) and Experiment 2 (open circles). If the adjusting-amount procedure produced steeper discounting (as indexed by higher values of k) than the adjusting-delay procedure, then the points would tend to fall above the dashed line; similarly, if the adjusting-delay procedure produced steeper discounting, the points would tend to fall below the dashed line. As may be seen, there were no systematic differences between the two procedures with respect to the degree of discounting.

GENERAL DISCUSSION

The question of interest in the present study was whether similar discounting of delayed food rewards is observed when pigeons are studied using adjusting-amount and adjusting-

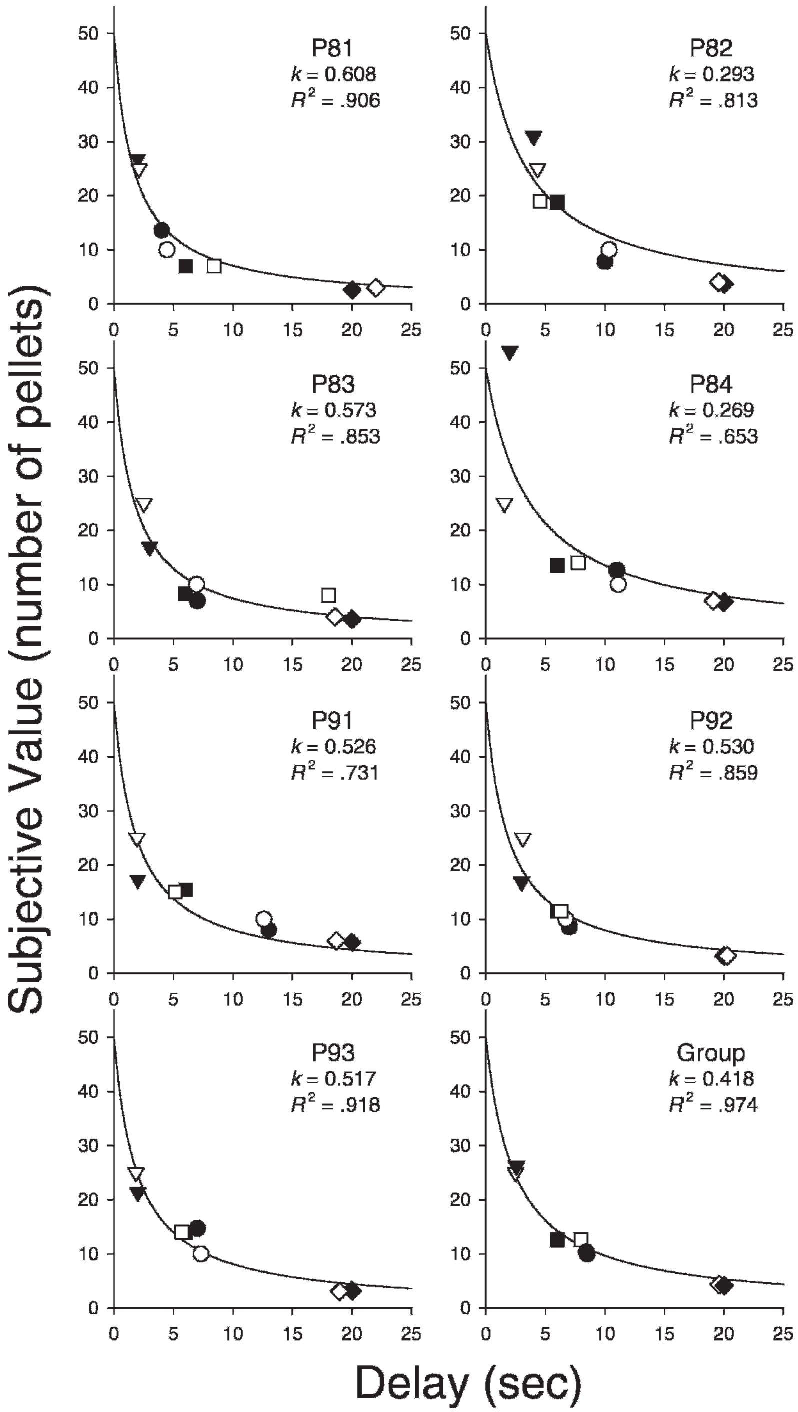

Fig. 2. Subjective value of the delayed 50-pellet reward as a function of time until its delivery. Data are from Experiment 2; results for individual pigeons, as well as group means (lower right graph), are shown. Open symbols represent data from the adjusting-delay procedure; filled symbols represent data from the adjusting-amount procedure. Each pair of same-shaped symbols (e.g., triangles) represents a pair of yoked conditions. Curves represent the best-fitting simple hyperbola (Equation 1).

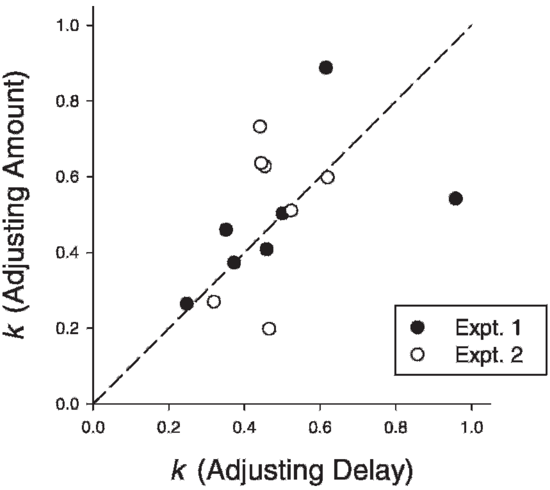

Fig. 3. Individual estimates of k for the adjusting-amount procedure as a function of the individual estimates for the corresponding adjusting-delay procedure from both Experiment 1 (filled circles) and Experiment 2 (open circles). If the adjusting-amount and adjusting-delay procedures produce similar degrees of discounting, then the points should fall along the dashed line.

delay procedures. There was no evidence of any systematic difference in the shape of the discounting function or in the degree of discounting in either Experiment 1 or Experiment 2. With regard to the shape of the discounting function, the data from both procedures were reasonably well described by a simple hyperbola (Equation 1). Moreover, there was little evidence of a systematic pattern in the residuals such as that often observed in human data (over-estimation of subjective value at brief delays and under-estimation at long delays). Such a pattern would indicate that the data would be better described by a hyperboloid function similar to Equation 1 except with the denominator raised to a power less than 1.0 (Green & Myerson, 2004; Myerson & Green, 1995). In the present case, however, and consistent with previous studies of discounting in animals, a simple hyperbola suffices to describe the data (Green et al., 2004; Mazur, 2000; Richards et al., 1997).

With regard to the degree of discounting, there was no evidence that one procedure consistently produced steeper discounting than the other. Averaged across both experiments, the mean value of k for the adjusting-amount procedure was 0.501 (standard error = 0.051) whereas the mean k for the adjusting-delay procedure was 0.484 (standard error = 0.046). Taken together, these findings of both qualitative and quantitative equivalence provide strong support for the hypothesis that the same discounting process underlies behavior on both procedures.

In Experiment 1, the adjusting-delay data appeared to be somewhat more orderly than the adjusting-amount data, as indicated by the fact that fits of the hyperbolic discounting function to the adjusting-delay data yielded a higher mean R^2 (.911 vs. .860). It seemed possible that this difference was because the accuracy with which the subjective value of the delayed reward could be measured was limited by the size (20 mg) of the food pellets. Therefore, smaller (14 mg) pellets were used in Experiment 2 in order to measure subjective value with greater precision. The fit to the combined data from both procedures was better in the second experiment than in the first (R^2 = .974 vs. .946), but the adjusting-delay data were again slightly more orderly (.913 vs. .788). We would note, however, that although fits to the adjusting-delay data yielded higher R^2s in both experiments, in both cases the difference was not statistically significant. From a practical perspective, moreover, there was little difference between the procedures with respect to the median number of sessions required to obtain stable estimates of subjective value.

In addition, fairly good correspondence between behavior on the two procedures was observed at the level of individual exposures to a procedure. Recall that pigeons first were tested using one procedure in order to generate predictions as to their behavior on the other, yoked procedure. In two of the yoked pairs of procedure in each experiment, the pigeons first adjusted the time to a large delayed reward until the delayed reward was judged equal in value to a fixed, smaller amount of immediate reward, and then chose between the delayed reward and an immediate reward, adjusting its amount until the immediate reward was judged equal in value to the delayed reward. At issue was whether, in the second procedure of the pair, they would adjust the number of immediate pellets until it was the same as that in the first procedure. As may be seen in the top graph of Figure 4, which shows the group means of the number of pellets for the second, yoked procedure of the pair as a percentage of its predicted value (i.e., the amount of immediate reward in the first procedure), there was good correspondence between observed and predicted amounts in both experiments.

In the other two pairs of procedures in each experiment, the pigeons first adjusted the number of immediate pellets until the value of the delayed reward was judged equal to that of the immediate reward. The second, yoked procedure then used that amount for the immediate reward, and the issue was whether the pigeons would adjust the delay to the large reward until it was equal to that in the first procedure. As may be seen in the bottom graph in Figure 4, the correspondence between observed and predicted values was good in two cases, the smaller amount in Experiment 1 and the large amount in Experiment 2. In the other two cases, the pigeons adjusted the delay to a longer duration than that in the initial adjusting-amount procedure, but taken together, the data from the two experiments do not appear to indicate a reliable or systematic bias.

Previous studies using adjusting-amount procedures have reported good fits of Equation 1 (e.g., Green et al., 2004; Richards et al., 1997) as have previous studies using adjusting-delay procedures (e.g., Mazur, 1987). The one study (Mazur, 2000) that used both procedures did so in two separate experiments with different subjects. Quite different estimates of k were obtained in the two experiments, but two factors make the difference in k difficult to interpret. First, different subjects were used, and second, the choice in the experiment that used an adjusting-delay procedure was between two delayed rewards, whereas the choice in the experiment that used an adjusting-amount procedure was between an immediate and a delayed reward. Research with humans has shown that the rate at which the value of the more delayed reward is discounted decreases as the delay to the sooner reward increases (Green, Myerson, & Macaux, 2005). Thus, one might expect shallower discounting in the adjusting-delay experiment with two delayed rewards, as indeed Mazur (2000) observed. Because of the differences in subjects, however, the difference in k is not readily interpretable. In contrast, the results of the present study suggest that estimates of k obtained from the same subjects performing both adjusting-amount and adjusting-delay procedures are highly similar.

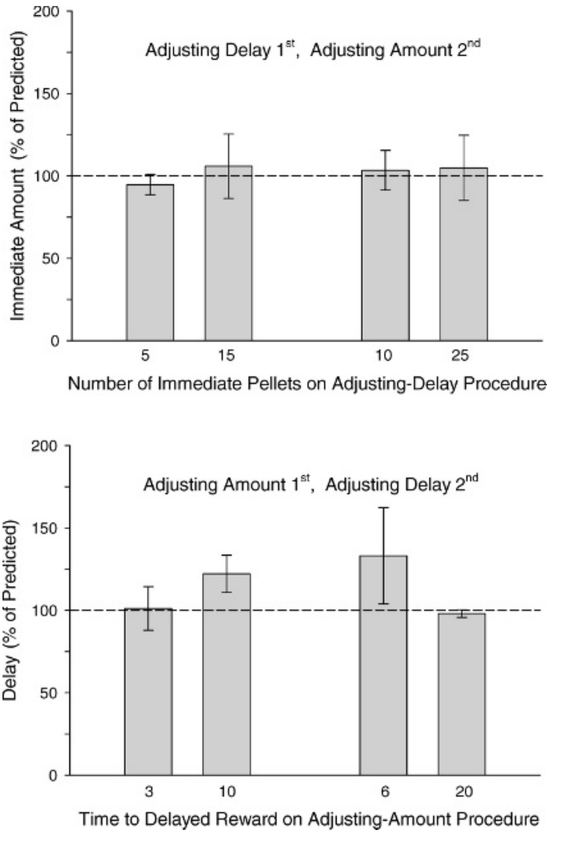

Fig. 4. Indifference points obtained with the second, yoked procedure of each pair as a percentage of the corresponding points obtained with the first procedure (predicted values) for both experiments. The top graph shows the mean percentages from pairs in which the adjusting-delay procedure preceded the adjusting-amount procedure; the bottom graph shows the mean percentages from pairs in which the adjusting-amount procedure preceded the adjusting-delay procedure. The error bars represent the standard error of the mean.

Sidman (1960) has noted that a systematic replication provides a test of both the generality of a phenomenon and its theoretical interpretation. In the present case, the fact that similar results were obtained with delayed rewards consisting of fewer, larger pellets (Experiment 1) and with delayed rewards consisting of more, smaller pellets (Experiment 2) represents a relatively small increase in generality. In contrast, the fact that nearly identical estimates of the k parameter in the simple hyperbolic discounting function were obtained in the same subjects using both adjusting-amount and adjusting-delay procedures represents a much more significant extension of generality and provides strong support for the hypothesis that the same process underlies the discounting of delayed rewards on both procedures.

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